# ENERGISE Program Kickoff

**DOE Award #: DE-EE0007999**

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy


## Enhanced Control, Optimization, and Integration of Distributed Energy Applications (Eco-Idea)

**NREL – PI: Murali Baggu**

October 11, 2017

# Project Team

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## NREL

**DEHC architecture, design, and development**
Lead: Murali Baggu (15% FTE)
Team: Emiliano Dall'Anese (15% FTE)

**Fast regulation capabilities**
Lead: Emiliano Dall'Anese
Team: Kyri Baker (5% FTE)

**System modeling and simulation**
Lead: Murali Baggu
Team: Fei Ding (30% FTE)

**PHIL test, application and visualization**
Lead: Bryan Palmintier (5% FTE)
Team: Kumaraguru Prabakar (5% FTE)

**Cyber security design and test**
Lead: Erfan Ibrahim

## Subs

### Schneider Electric

**Providing ADMS modeling, simulations, integrations, development and field demonstrations**

Lead: Scott Koehler (10% FTE)

Team: Branislav Brbaklic (4% FTE), Ivana Krstic (2% FTE), Jugoslav Dujic (2% FTE), Martin Brock (2% FTE), Sean Fenton (10% FTE), Sonja Kanjuh (2% FTE), Xiaolei (Melody) Zhang (2% FTE)

### Varentec Inc.

**Providing ENGO® devices and GEMS™, GEMS™ interface implementation, field demonstration of ENGO® devices**

Lead: Rohit Moghe (15%FTE)

Team: Mehrdad Hamadani (4% FTE), Damien Tholomier (4%FTE), Frank Castaneda (30% FTE)

### Xcel Energy

**Providing feeders and field demonstration**

Lead: Eric Gupta (10% FTE)
Business contact: Brian Amundson (4% FTE)

### EPRI

**Interoperability design and test**

Lead: Brian Seal (10% FTE), Gerald Gray (10% FTE)

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Schneider Electric

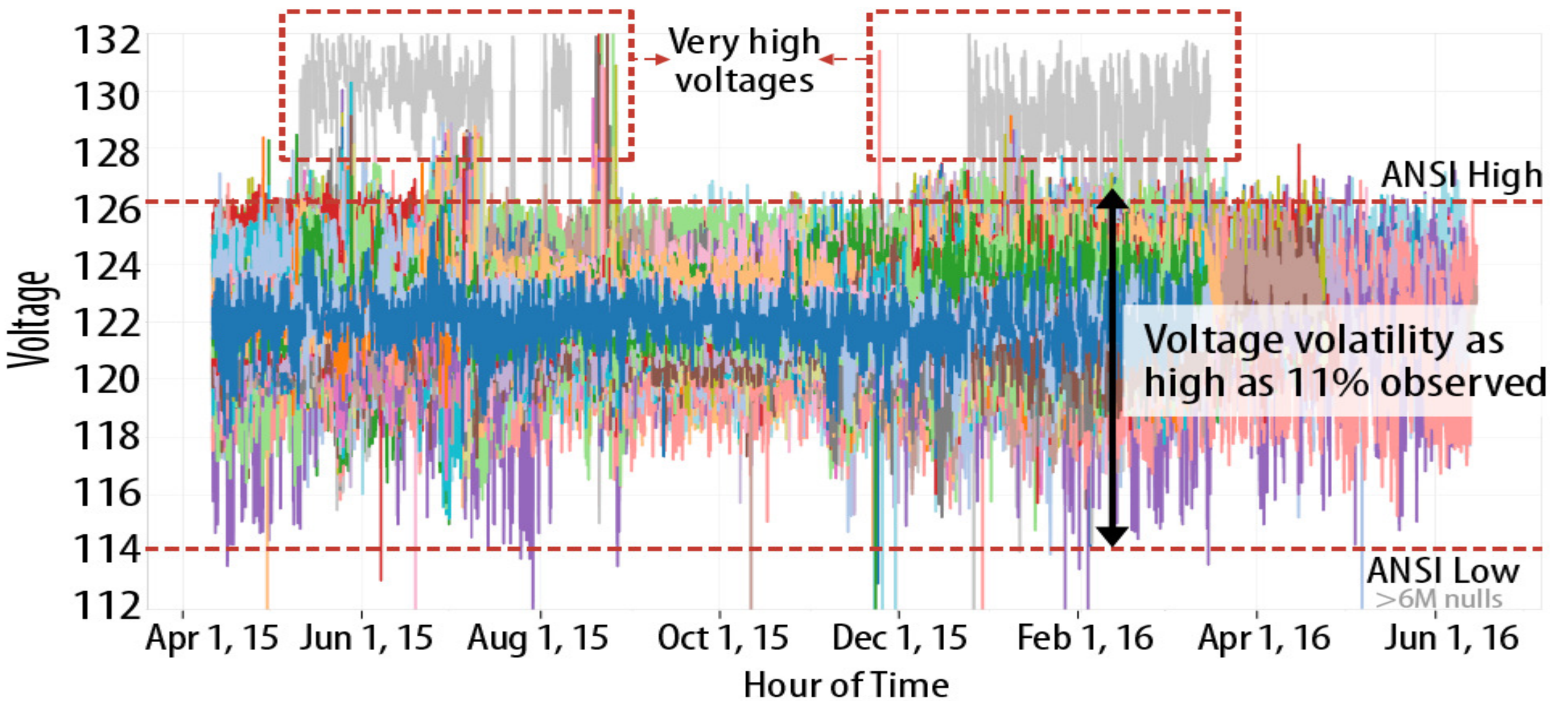
varentec

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Xcel Energy® RESPONSIBLE BY NATURE™

AUSTIN ENERGY®

## The problem




*Voltage variability at the grid edge measured by 1,005 AMI meters collected over 14 months*

# Project Goals

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# Project Goals



- Overvoltage conditions
- Transients from variability of renewable generation
- Stochasticity of loads

**Weaknesses**:

- lack of situational awareness
- heuristic and slow-acting control
- latency of control for emergency
- Do not tap into communications

# Project Goals

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Eco-Idea - Innovative **Data-Enhanced Hierarchical Control architecture** that**:**

- ❑ Seamlessly integrates ADMS, real-time OPF, and VAr support
- ❑ Real-time monitoring and forecasting
- ❑ Planning to provide what-if analysis
- ❑ Is flexible, interoperable, and vendor-agnostic

# Project Goals

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Eco-Idea - Innovative **Data-Enhanced Hierarchical Control architecture** to meet the target requirements:

- **50% relative to the peak load**
- **125% relative to daytime minimum load**
- **20% by annual energy production**

# Project Goals



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- ❑ Transients from variability of renewable generation
- ❑ Stochasticity of loads

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Eco-Idea - Innovative **Data-Enhanced Hierarchical Control architecture** to meet the target requirements:

- Intercon. Review and Approval Time: 1) one day for residential settings, 2) less than five days for utility setups
- SAIDI/SAIFI, ANSI 84.1, and NERC requirements will be fully satisfied
- All the other ENERGISE requirements …

# Project Goals

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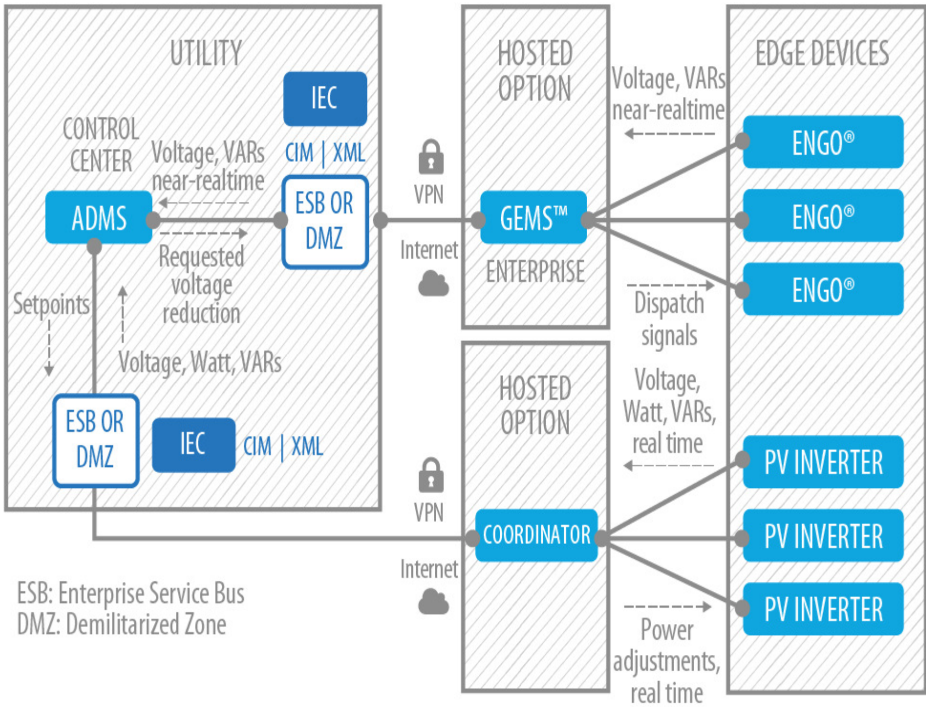
Unified solution to tackle the critical challenges associated with *Enhanced System Layer*, *Traditional System Layer*, *Telecom & Data Layer*, and *Local Device Layer*.



# Project Goals

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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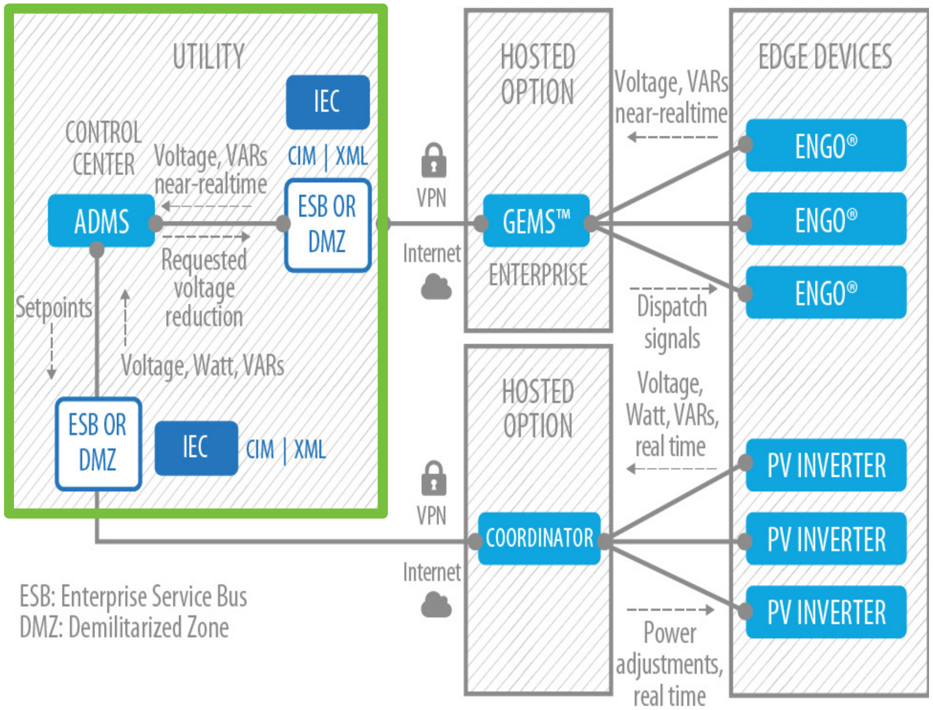
- *Utility enterprise*



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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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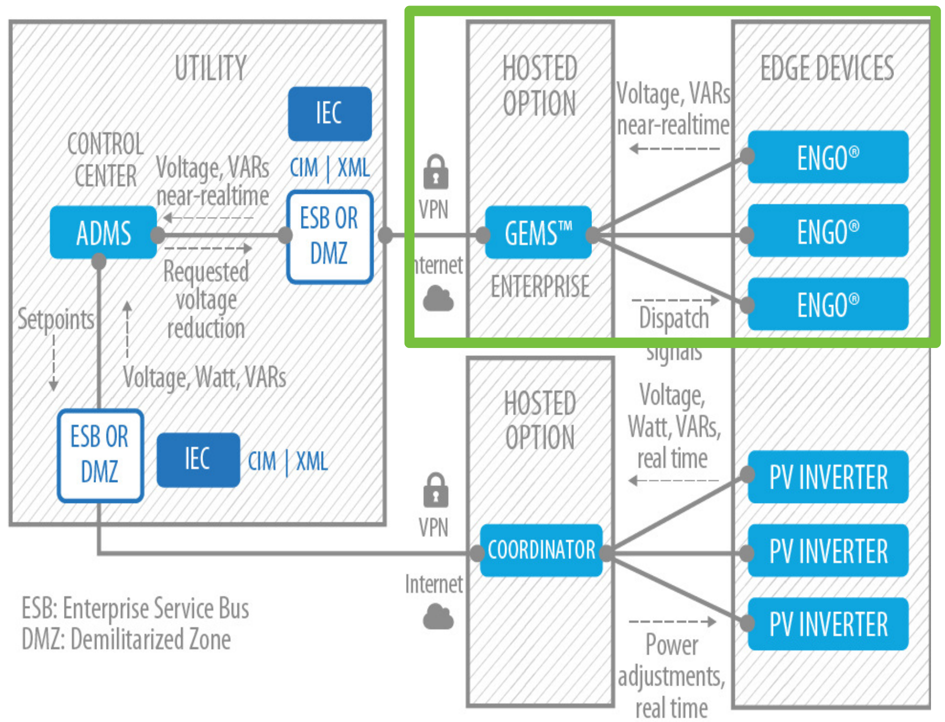
- *Utility enterprise*
- *Varentec* ENGO® devices



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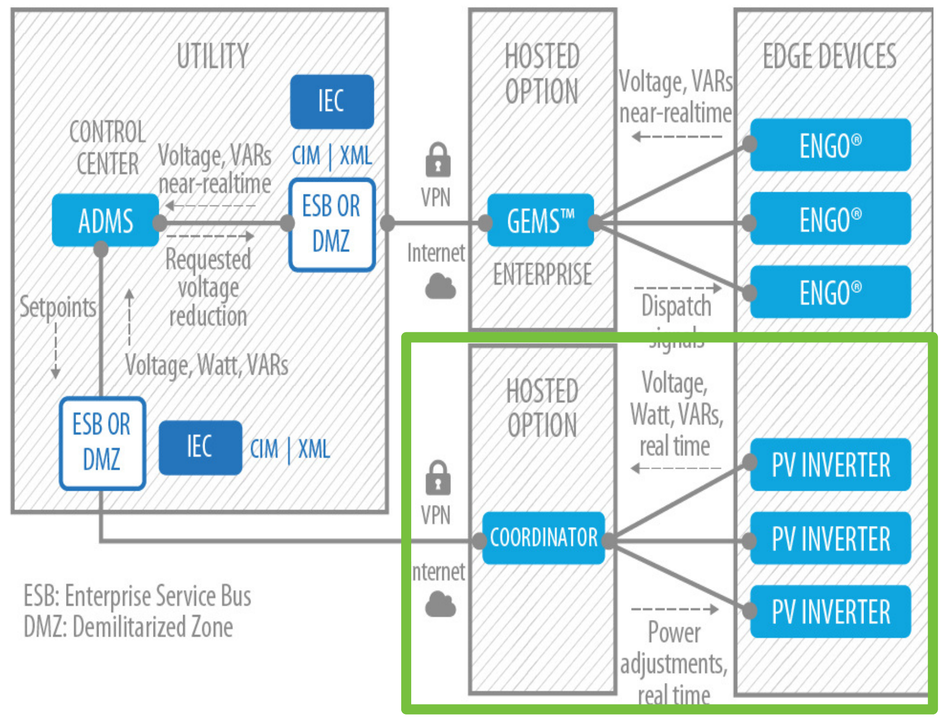
- ❑ *Utility enterprise*
- ❑ *Varentec* ENGO® devices
- ❑ *Real-time optimal power flow*



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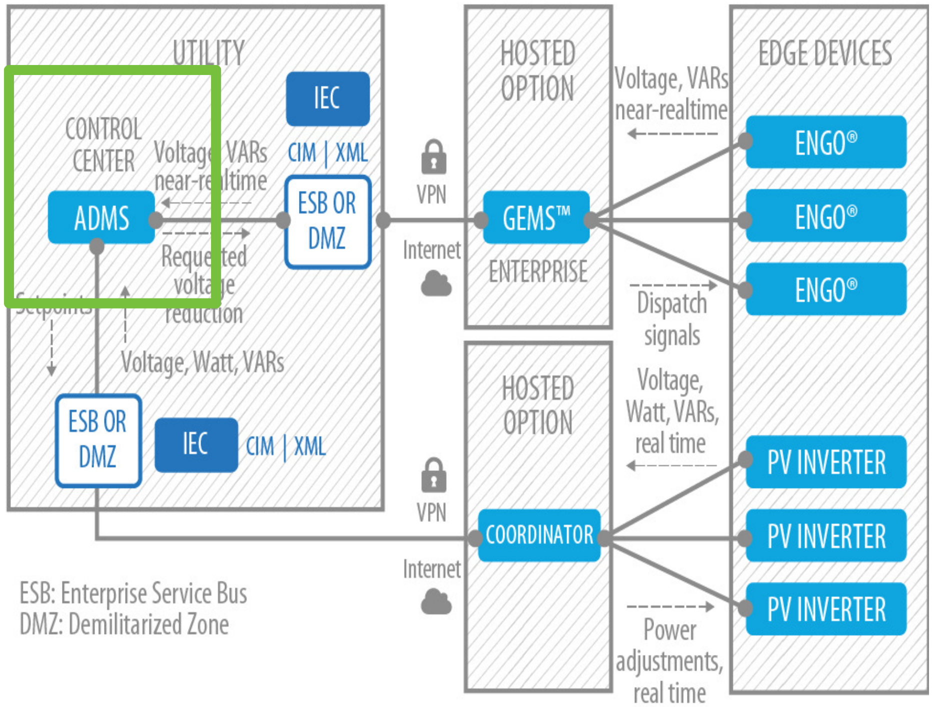
- *Real-time optimal power flow*
- *State estimation, forecasting*



# Project Goals



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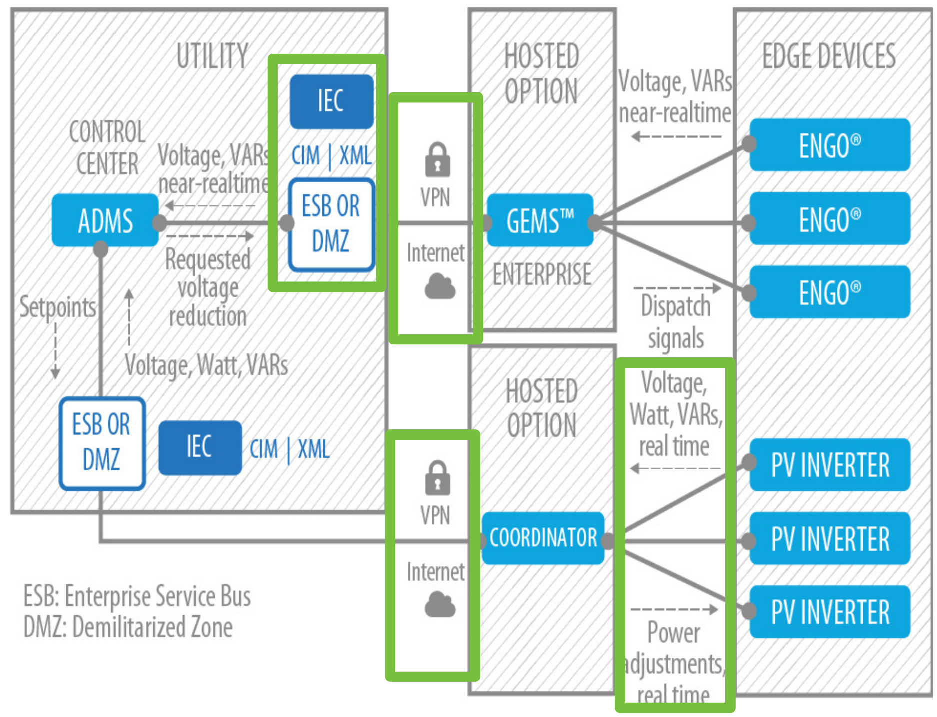
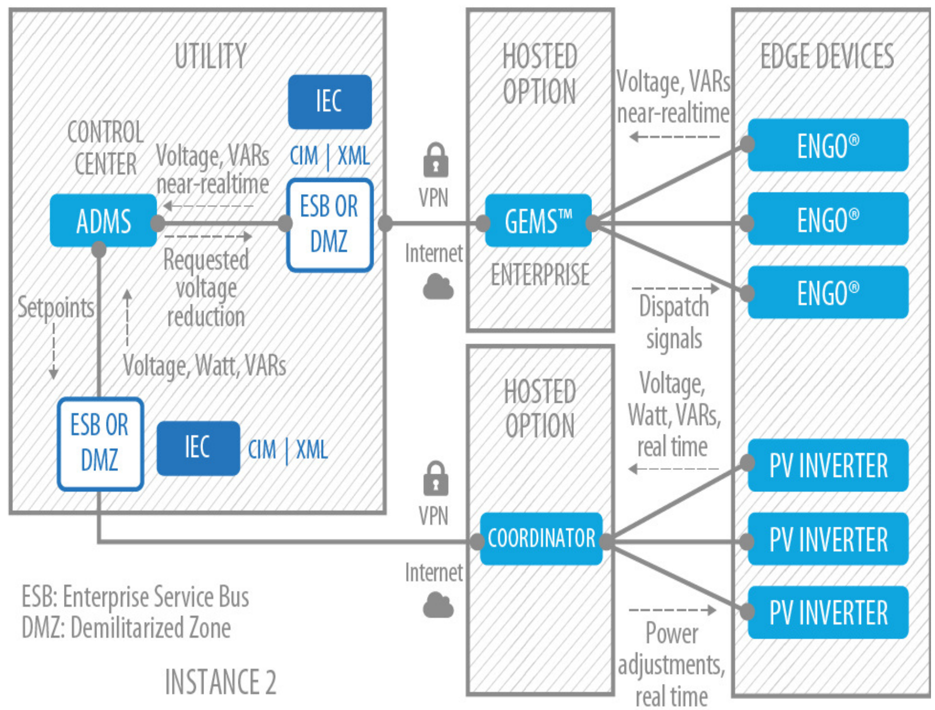
- ❑ *Utility enterprise*
- ❑ *Varentec* ENGO® devices
- ❑ *Real-time optimal power flow*
- ❑ *State estimation, forecasting*
- ❑ *Cybersecurity and interoperability*



# Project Architecture

Unified solution to tackle the critical challenges associated with *Enhanced System Layer*, *Traditional System Layer*, *Telecom & Data Layer*, and *Local Device Layer*.



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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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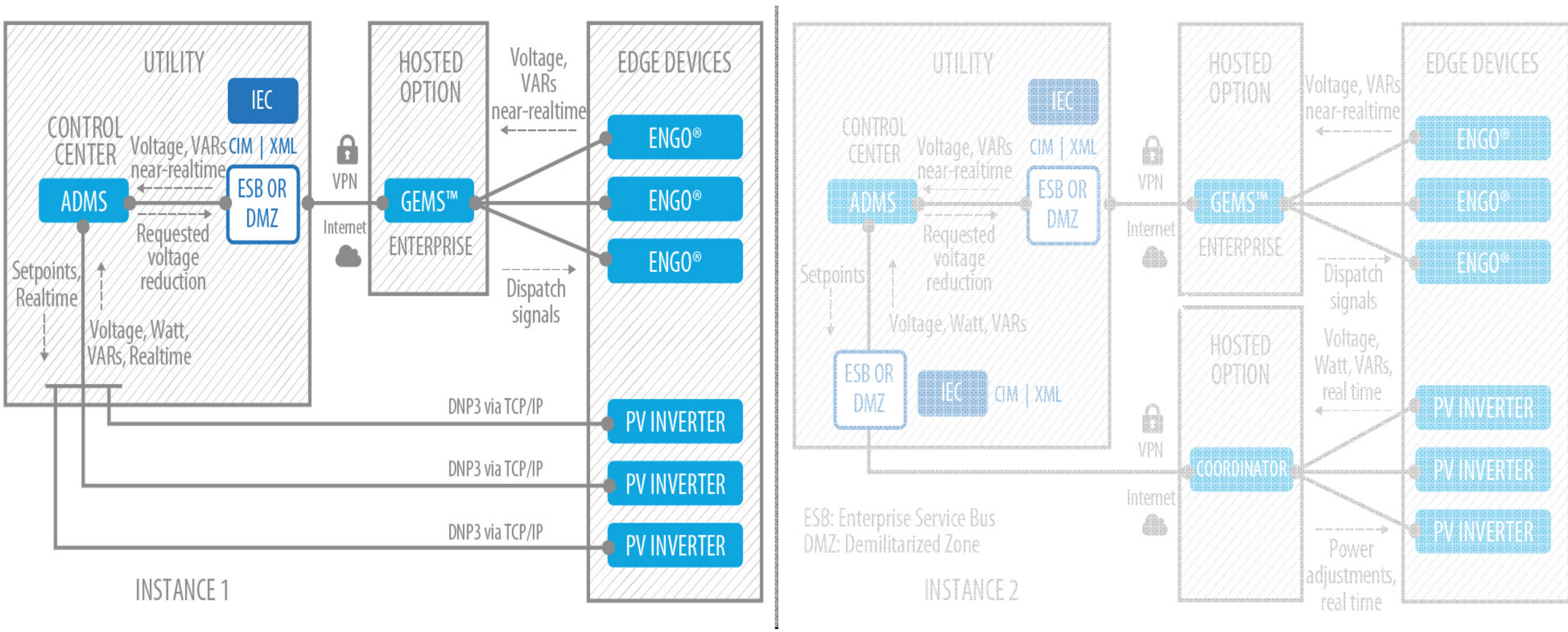
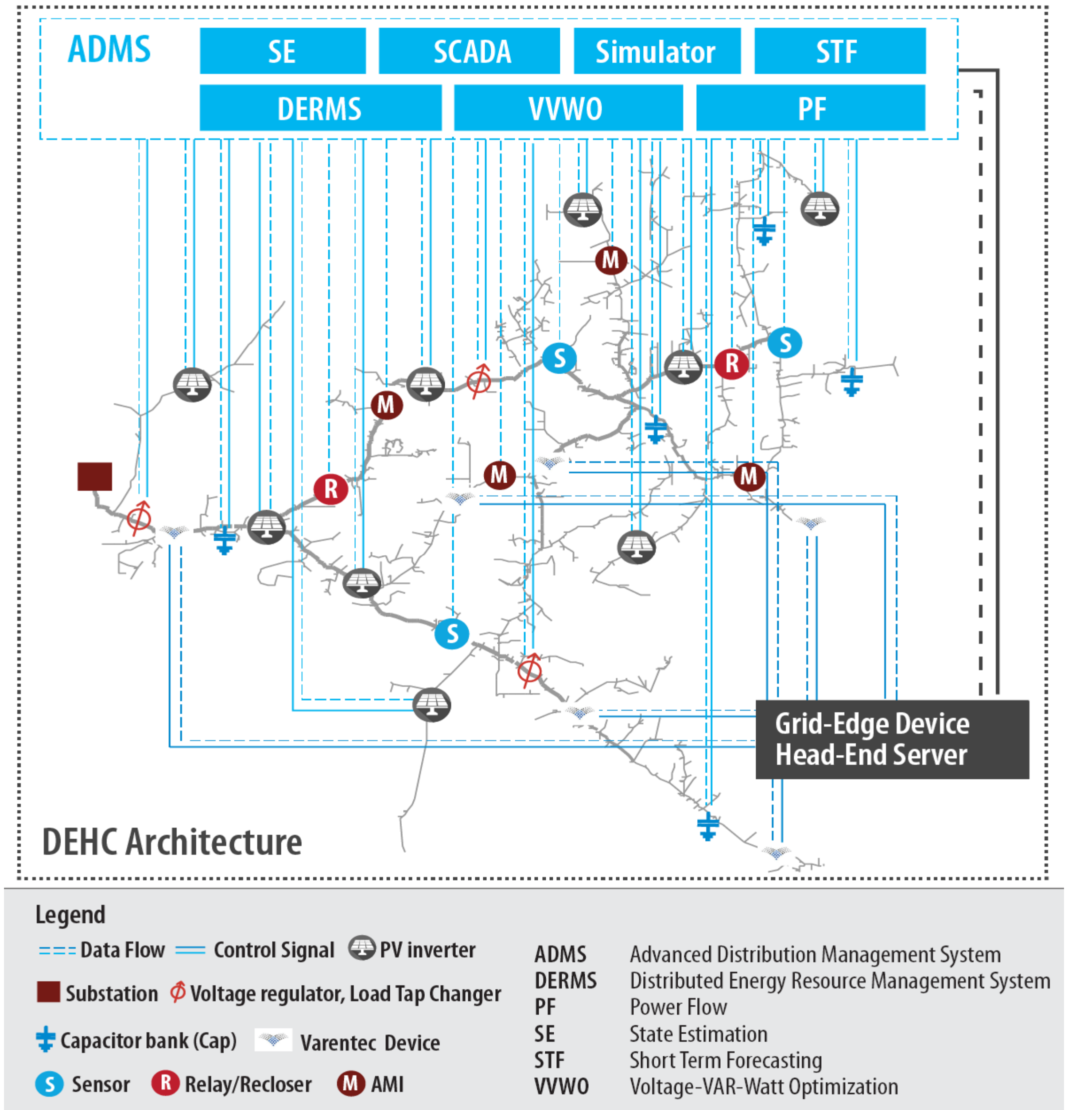


# Project Goals

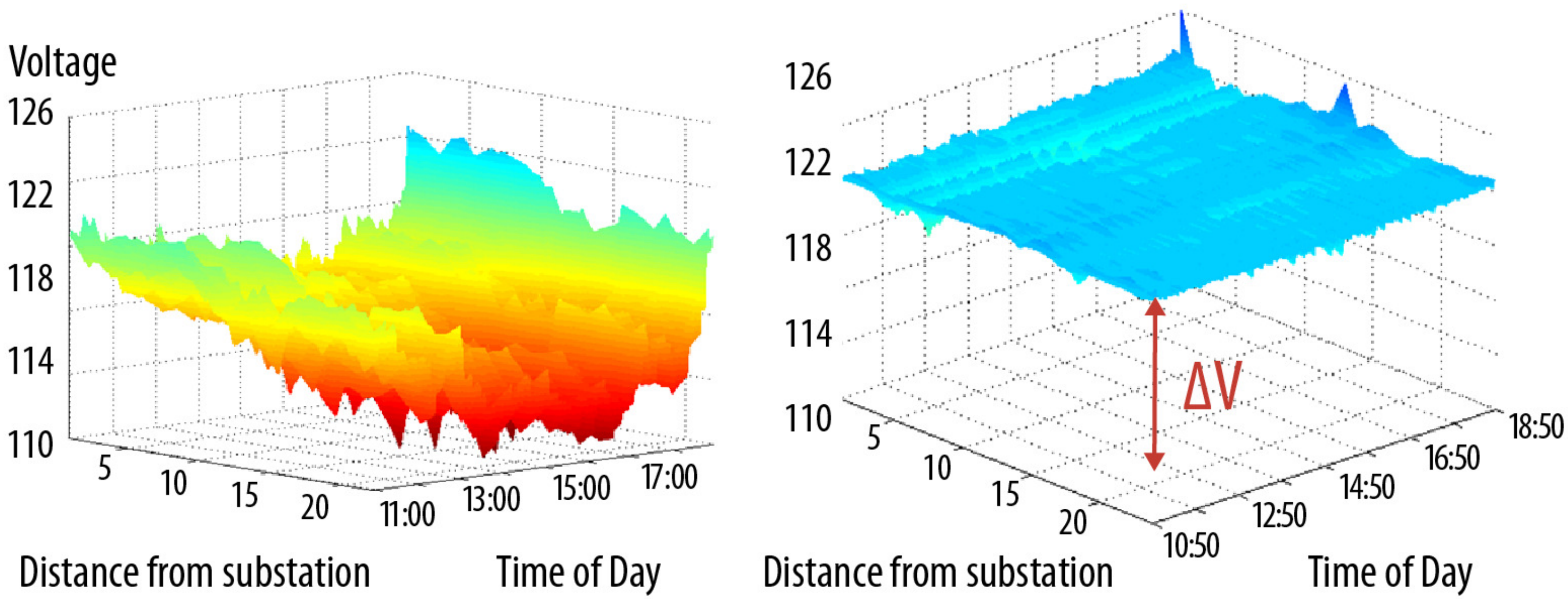
***(1) ADMS***

- Advanced applications for network analysis, diagnosis, prognosis, and control
- Advanced model-based optimizations
- Forecasting
- Commands to field devices such as tap changers, capacitors, smart PV inverters



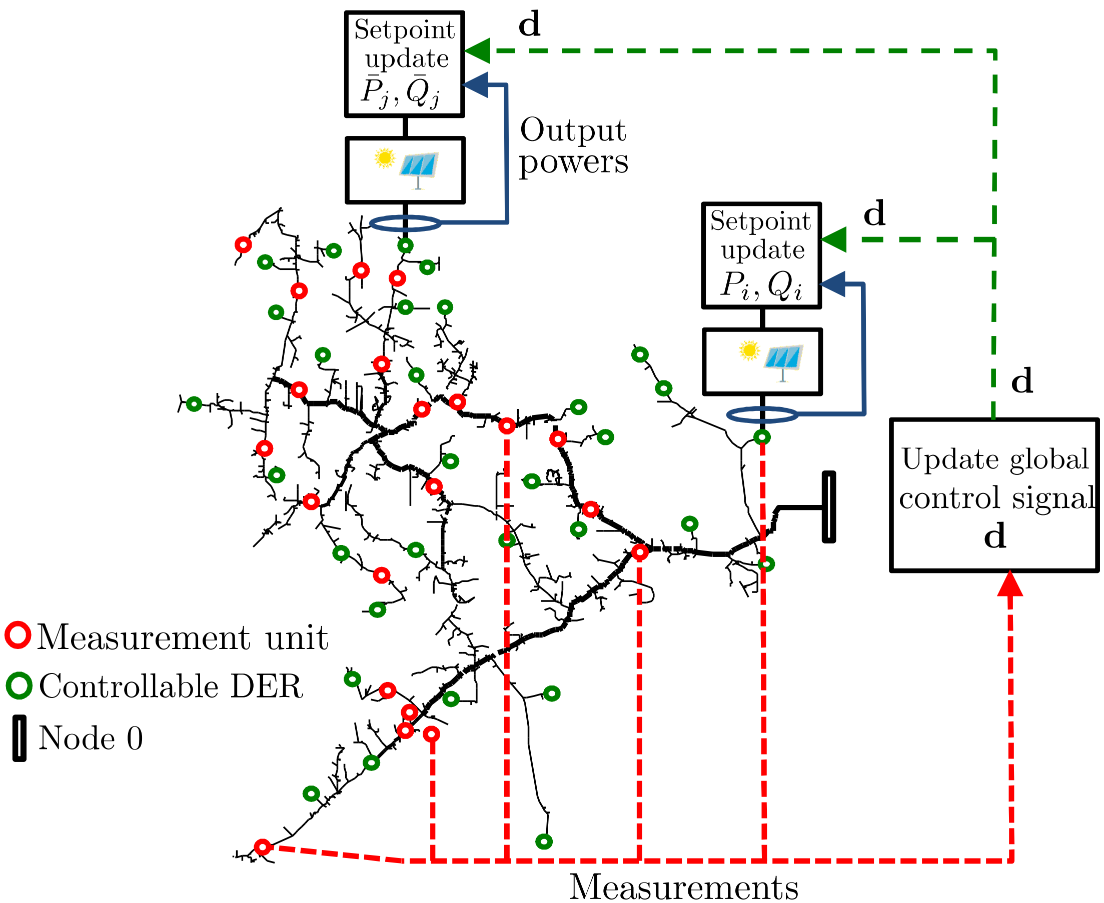
### *(2) ADMS-ENGO synergy*

- Varentec's ENGO® devices: increased flexibility in controlling voltage profile
- Interface between GEMS™ and ADMS to achieve coordination
- Standard protocols such as DNP3 to achieve interoperability



### *(3) Real-time optimal power flow*

- **Unique contribution of our team** [Dall'Anese at al'14, Bernstein at al'14]




- Real-time (second level)
- Self-optimizing
- Distributed
- Stable
- Optimal

# Project Goals

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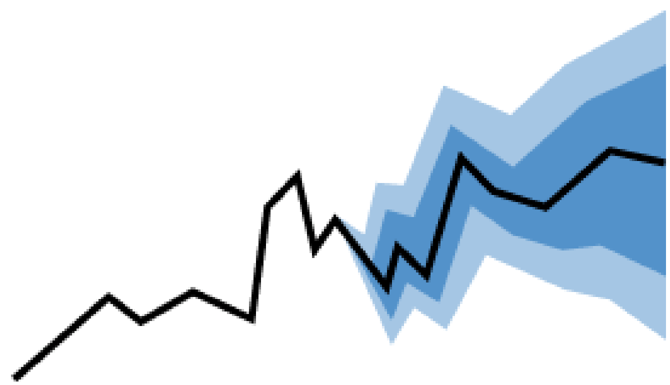
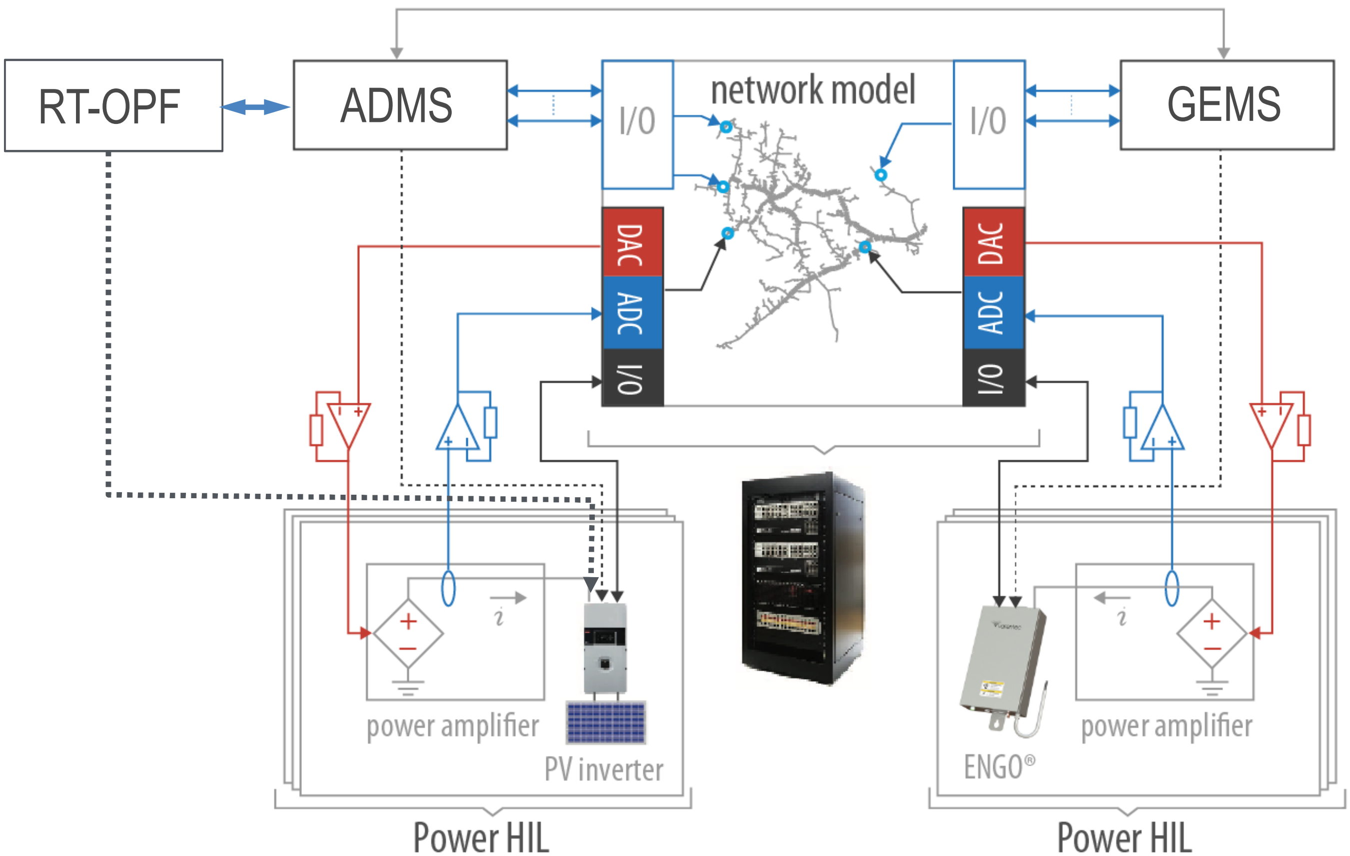
***(3) Comprehensive situational awareness***

- **State estimation**
  - Estimates distribution network state (with remotely monitored data and predicted loads)
  - Combines telemetered real-time and model data into a consistent set of state variables
- **Short-term load forecasting**
- **Short-term solar forecasts**
  - Near-term solar forecasts from 0-3 hours
  - Forecasts beyond 3 hours will be derived from available operational weather forecasts that use numerical weather prediction models



# Project Goals

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy




- Replicate real-world utility feeders with more than 10,000 virtual nodes
- All the five components of the architecture will be tested

# Project Goals

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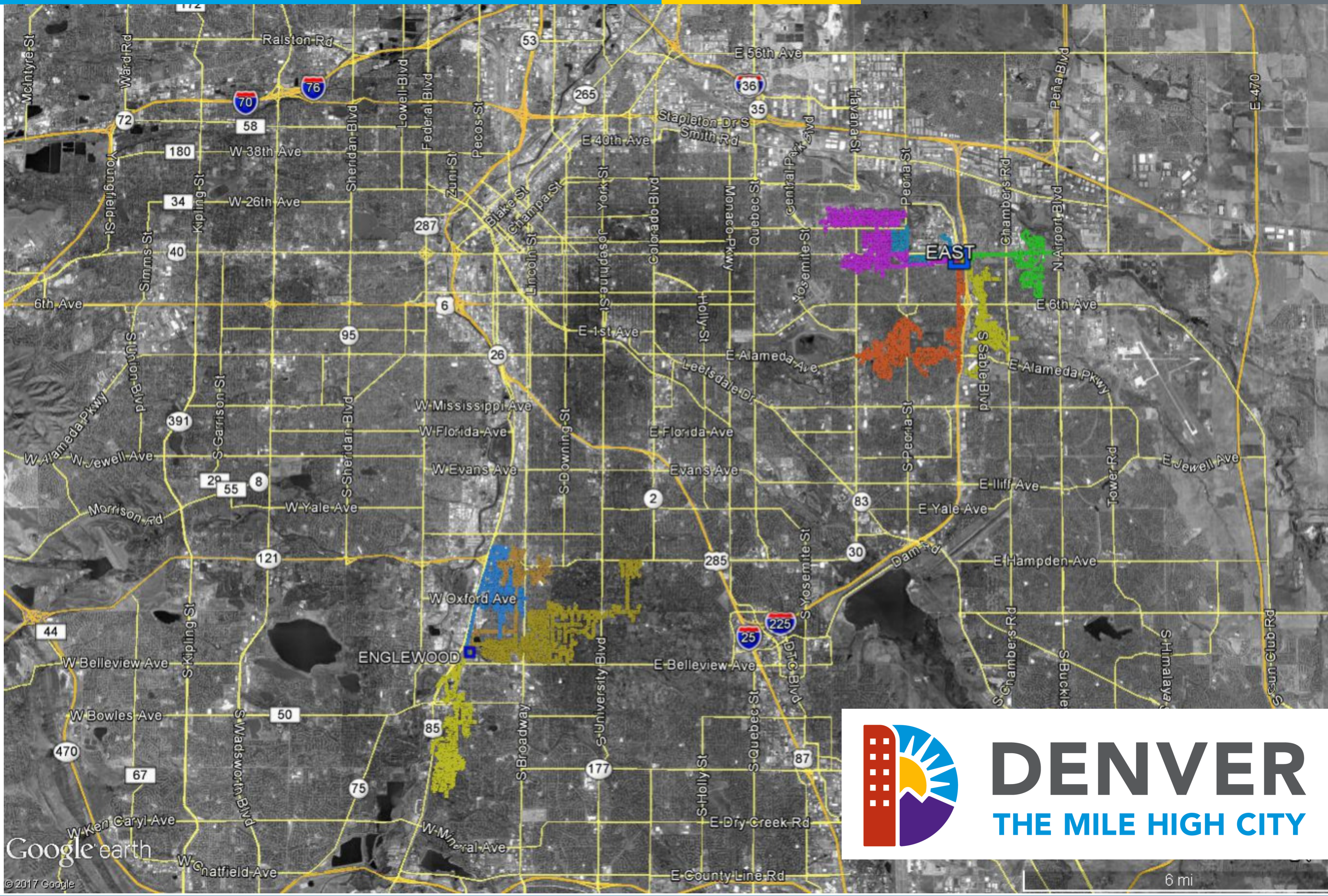
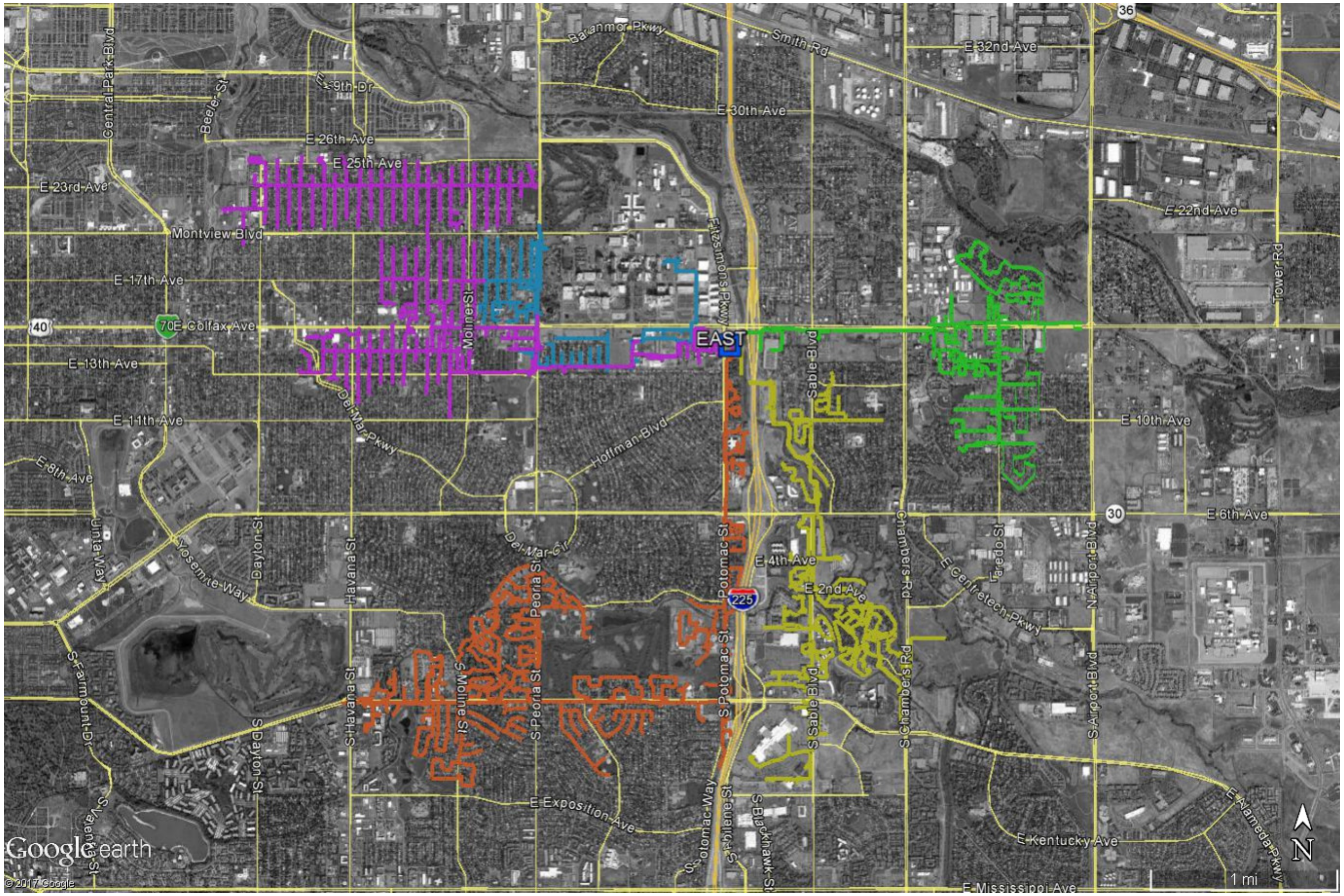


# Project Goals






- At least 100 physical nodes
- ADMS + Varentec + cyber security + interoperability
- No real-time OPF

# Major Innovations

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- ❑ Unique approach to distribution system operation that **has not been developed, tested, and validated before**.

- ❑ Manage the entire distribution system and all the assets residing in **each layer**; enable a seamless integration of conventional devices and DERs implementing advanced control schemes

- ❑ Support **the co-existence** of various control techniques to provide optimal operations with high penetration of solar power

- ❑ First-of-its-kind effort to integrate and advance technologies that are currently operating in a distinct and decoupled way

# Major Innovations

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- **First-of-its-kind deployment** and to provide ample evidence of the effectiveness of the proposed technology and will propagate benefits to the broader utility, industrial, and power-engineering sectors.

- **Real-time distributed OPF** is a new paradigm first proposed by us. NREL is the first to test real-time OPF on P-HIL.

  - [Dall'Anese at al'14] and [Bernstein at al'14]
  - [Bolognani at al'15]
  - [Dall'Anese at al'16]
  - [Gan-Low'16]
  - [Dall'Anese at al'17]
  - [Tang-Low'17]
  - …

# Main Project Tasks/Subtasks

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| | | Budget Period 1 | | | | Budget Period 2 | | | | Budget Period 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Task # | Item Description | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| 1 | **Select utility distribution feeders for field demonstration** | ■ | | | | | | | | | | | |
| 2 | **Develop DEHC architecture** | ■ | ■ | ■ | ■ | | | | | | | | |
| 3 | **Ensure Cybersecurity and Interoperability of DEHC architecture** | | | ■ | ■ | | | | | | | | |
| 4 | **Define test plans for PHIL co-simulation** | | | ■ | ■ | | | | | | | | |
| 5 | **Develop and test GEMS™-to-ADMS interface** | | | | | ■ | ■ | ■ | | | | | |
| 6 | **Execute PHIL test plans** | | | | | ■ | ■ | ■ | ■ | | | | |
| 7 | **Develop visualization capability** | | | | | | ■ | ■ | ■ | | | | |
| 8 | **Deploy ENGO® hardware devicesand other hardware equipment in the field** | | | | | | | ■ | ■ | | | | |
| 9 | **Demonstrate DEHC architecture in the field** | | | | | | | | | ■ | ■ | ■ | ■ |
| 10 | **Analyze techno-economic benefits** | | | | | | | | | | ■ | ■ | |
| 11 | **Disseminate results and transfer technology** | | | | | | | | | | | | ■ |

# Project Milestones/Deliverables

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**Year One Milestones**:

- Architecture design
- Feasibility assessment of DEHC architecture for a variety of operational setting and vendor technologies (ADMS, smart inverters, and grid-edge devices)
- Test plan for laboratory PHIL/CHIL testing of the

**Year Two Milestones**:

- Control, interoperability and cyber security assessment of the architecture at NREL

**Year Three Milestones**:

- Demonstrate elements of DEHC architecture in the field
- Techno-economic analysis
- Disseminate techno-economic analysis on the field deployments

# High Risks & Mitigation

| High Risks | Mitigation |
|---|---|
| The adoption of the proposed integrated approach where distributed control algorithms and autonomously controlled devices seamlessly interact and co-exist with ADMS will require a shift from current operational practices | The team is uniquely poised to pave the way to transformation because it includes leading experts in power systems modeling, distributed control, and optimization, as well as an ADMS vendor, device manufactures, and utility companies |
| A system that integrates control layers that run at seconds level to minutes has never been tested before | This is a technical risk, which can be managed with exhaustive PHIL testing Integration of GEMS$^{TM}$ and ADMS is a new endeavor |
| Integrating completely different platforms is always a challenge and poses a technical risk | Specifying the protocols, using open standards, and laying out at the beginning of the project the requirements and constraints of the interface layer |

# Interoperability

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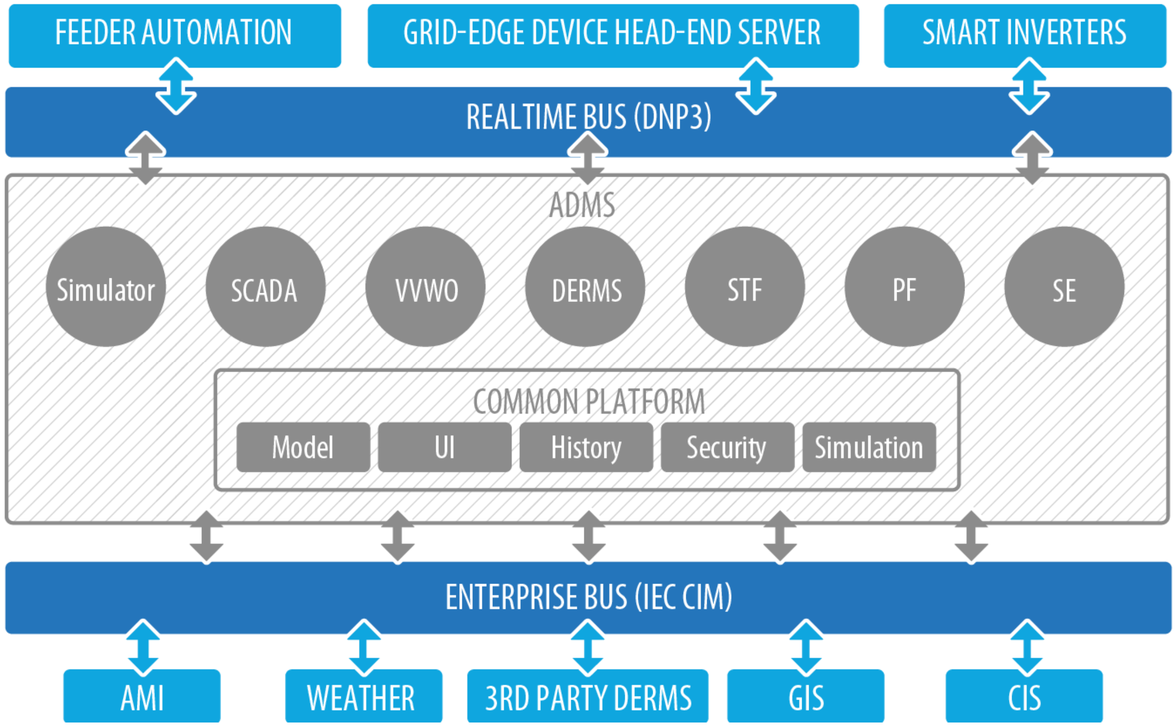
**Real-time bus (DNP3):**

- Standard smart inverter functions identified in the IEC 61850-7-520
- Information model IEC 61850-7-420
- The DNP3 AN 2013-001 protocol




**Enterprise Bus:**

- IEC Common Information Model (CIM)
- This will be done using the EPRI DER Group-Management functions and standard IEC CIM 61968 information model and messages.

# Cyber security

**Some features …**

- ❑ High-performance firewall and VPN login.
- ❑ Updates of software security patches.
- ❑ Access control lists on all Layer 2/3 switches with restrictions on inter-VLAN
- ❑ Network segmentation with access control
- ❑ Disable unused ports
- ❑ Port security for all used ports locked in by MAC address of authorized devices
- ❑ In-line blocking devices with Transport Layer token authentication
- ❑ Signature-based SCADA malware detection.
- ❑ Network-based anomaly
- ❑ Business process security to identify anomalies in DNP3 and Modbus TCP protocols

# Thank You!

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Presented by: emiliano.dallanese@nrel.gov

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# Backup slides

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# Cost-Benefit Analyses

- A comprehensive cost-benefit analysis will be performed to calculate dollar value streams associated with:
  - Energy consumption
  - Energy production
  - Operational characteristics


- Value streams will be associated with:
  - PV production
  - Feeder losses
  - Frequency of operation of switching equipment on the feeder with the expected resulting requisite maintenance and replacement expenditures

# Anticipated Outcomes

- Unified operational solution that can address the critical challenges associated with *Enhanced System Layer*, *Traditional System Layer*, *Telecom & Data Layer*, and *Local Device Layer*

- DEHC architecture will be scalable and will identify the optimal communications and data exchanges between the various controllable assets

- The DEHC architecture will be *vendor-agnostic, fully interoperable, and can be implemented on any feeder.*

- The DEHC architecture will meet or exceed the following target requirements
  - **50% relative to the peak load**, as will be demonstrated in the HIL experiments and in at least one of the test feeders
  - **125% relative to daytime minimum load**, as demonstrated in the HIL experiments;
  - **20% by annual energy production**, as demonstrated in the HIL experiments

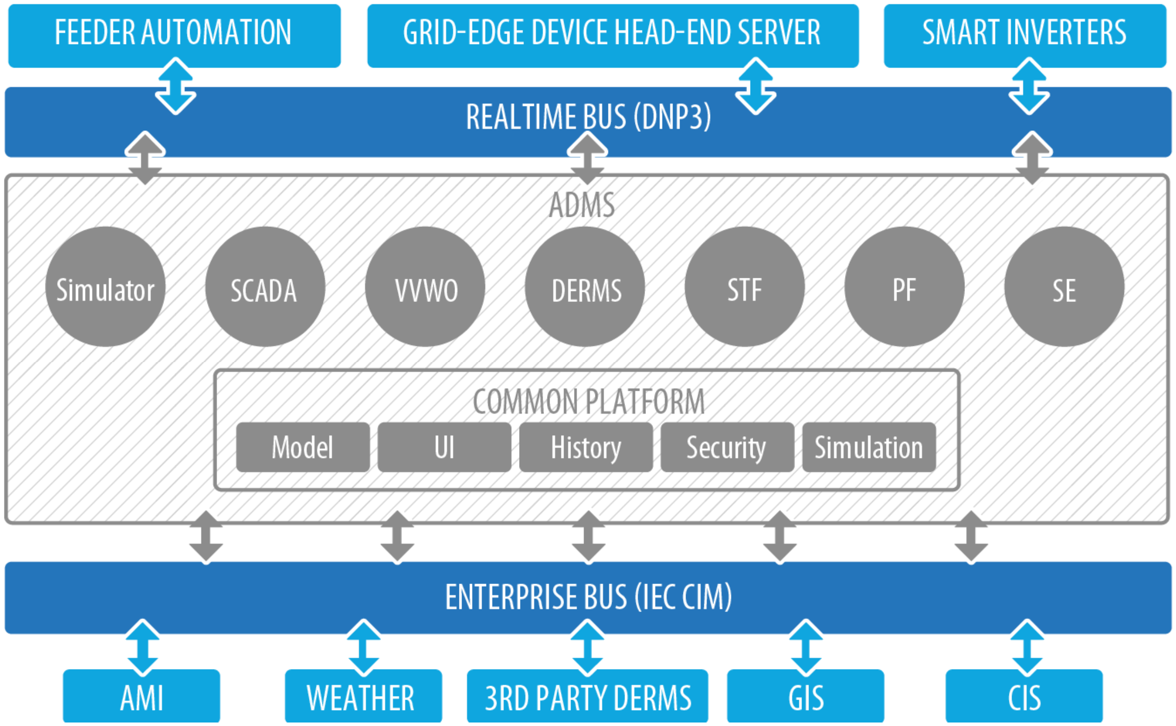
# Anticipated Outcomes

- Interconnection Review and Approval Time can be lowered to less than one day for residential settings, and less than five days for commercial/utility setups
- SAIDI/SAIFI, ANSI 84.1, and NERC requirements will be fully satisfied
- The system state will be observed every 10 minutes and day- and hour-ahead forecasts will be performed every hour
- The DEHC architecture will be fully interoperable and embraces well-established standards
- Computation cycles will be 5 minutes or less for operation, seconds for real-time control, and 30 minutes for operation planning
- Response-time requirements specified in the ENERGISE FOA will be met and will be demonstrated in both HIL experiments and in the field tests
- ADMS applications will be capable of analyzing all feeders from a single substation, perform feeder topology recognition, and execute VVWO

# Interoperability

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Real-time Bus (DNP3): The project will utilize the standard smart inverter functions identified in the IEC 61850-7-520 and associated information model in IEC 61850-7-420. The DNP3 AN 2013-001 protocol will be used to support these functions for directly-managed PV systems and to communicate with Grid-Edge head end server. The DNP3 protocol will also be used for the DMS connection to directly managed utility control devices (capacitors and voltage regulators).




Enterprise Bus, IEC Common Information Model (CIM): This interface broadly enables the hierarchical, extensible nature of the proposed system architecture. This architecture will be implemented by the ADMS vendor to communicate with different enterprise systems. Extending this concept, the architecture also enables microgrid controllers, facility management systems, vendor-managed distributed energy resources, utility-owned aggregation (e.g. a feeder-level controller) and third party aggregators to feed into the system using the same CIM-based enterprise interfaces. This will be done using the EPRI DER Group-Management functions and standard IEC CIM 61968 information model and messages.

# Cyber security



- Protection with a high-performance firewall and VPN login.
- Updates of software security patches to mitigate cyber risks from known vulnerabilities.
- Access control lists on all Layer 2/3 switches with restrictions on inter-VLAN
- Network segmentation with access control lists
- Disable unused ports on the firewalls and layer 2/3 switches to eliminate unauthorized access.
- Port security for all used ports locked in by MAC address of authorized devices with initial connection to avoid device swapping for cyber-attacks.
- In-line blocking devices with Transport Layer token authentication protecting all SCADA system nodes from unauthorized access.
- Signature-based SCADA malware detection IDS system.
- Network-based anomaly detection via tap for rapid identification of unauthorized access of the network from external and/or internal threats.
- Business process security IDS via tap to identify anomalies due to data fuzzing in power systems transactions in DNP3 and Modbus TCP protocols